Institute of Ionosphere

IZMIRAN

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BEHAVIOR OF GALACTIC COSMIC RAYS BEFORE AND DURING HIGH-ENERGY MAGNETOSPHERIC ELECTRON FLUX ENHANCEMENTS

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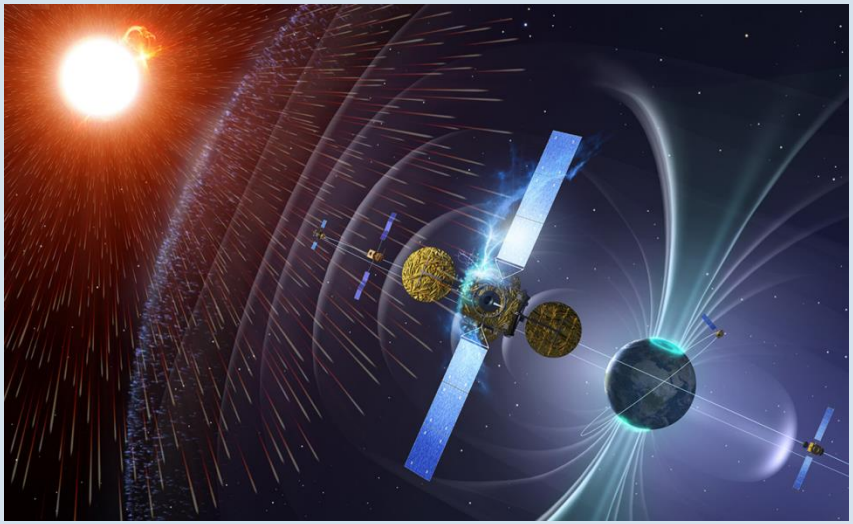


THE DANGER OF INCREASING OF HIGH-ENERGY MAGNETOSPHERIC ELECTRONS WITH E>2 MEV

Why is this task so important for Space Weather research?

Large enhancements in the fluxes of relativistic electrons lead to spacecraft malfunctions and have in a number of cases resulted in the failure of satellites. The anomalies were most frequently associated with false commands caused by internal electrostatic discharges.

SATELLITE MALFUNCTION DATA

The main contribution was from NGDC satellite anomaly database, created by Daniel Wilkinson.

+

"Kosmos" data (circular orbit at 800 km altitude and 74º inclination)

+

1994 year anomalies - Walter Thomas report (Thomas, 1995).

+ ε

Characteristics of satellites were taken from different Internet sources:

- http://spacescience.nasa.gov/missions/index.htm
- http://www.skyrocket.de/space/index2.htm
- http://hea-www.harvard.edu/QEDT/jcm/space/jsr/jsr.html
- http://www.astronautix.com/index.htm

Project INTAS-00-0810 **"Improvement of methods of control and prognosis of periods of dangerous influence of space weather on satellite's electronics"**

MODELS OF THE ANOMALY FREQUENCY

high alt.- low incl.

cc=0.40

- **e>2 MeV**
- Apd, AEd, sf
- Vsw
- p60d, p100
- da10

low alt.-high incl.

cc=0.21

- **e>2 MeV**
- CRA
- Apd, sf
- Vsw_{max}
- Bzd

high alt.-high incl.

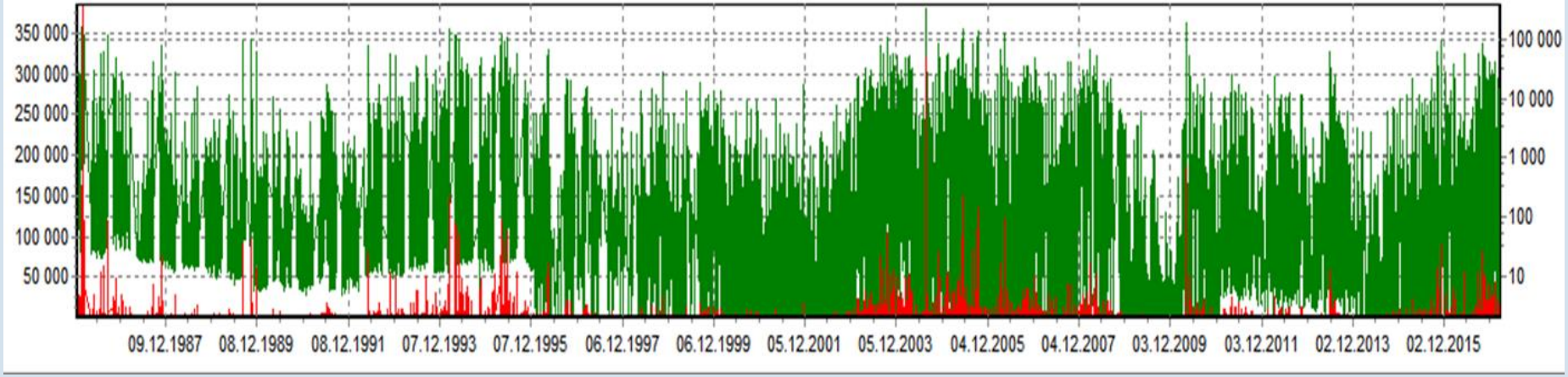
cc=0.51

- **p>100 MeV, p60d**
- Bznsum

Parameters that were used to simulate anomaly frequencies for different orbits are listed here (HL, LH and HH groups). **The electron flux is a key parameter in HL and LH groups, especially – in HL. In HH group, protons are much more important than other indices.**

Belov A., Dorman L., Iucci N., Kryakunova O., Ptitsyna N. The relation of high- and low-orbit satellite anomalies to different geophysical parameters.// in "Effects of Space Weather on Technology Infrastructure. NATO Science Series II, 2004, V.176, p. 147.

THE ELECTRON FLUX IN 1986-2016



High energy electron flux (>2 MeV) in 1986-2016

The daily fluence was chosen as the main characteristic of the >2 MeV electrons measured by the GOES satellites at geostationary orbits, since it was most closely associated with malfunctions of the satellites' electronic equipment.

In 1986–2016, daily fluence *F* of high-energy (>2 MeV) electrons measured by the GOES satellites varied within wide limits, from 1.4×10^4 to 9.3×10^9 electrons $(cm^2\ sr\ day)^{-1}$.

DATA USED

As main characteristics of magnetospheric electron fluxes in geostationary orbits the following were chosen: the particle flux directly measured on the GOES satellites (the number of particles·cm^{-2}·sr^{-1}·s^{-1}) and the diurnal fluence (total flux per day) of relativistic magnetospheric electrons with energies above 2 MeV.

Information about high-energy electrons, characteristics of solar and interplanetary activity is collected in the Solar and Geomagnetic Activity (SGA) database, created and maintained at IZMIRAN.

This database contains information on:

- **Diurnal electron fluences obtained onboard the GOES satellites over a 35-year period (1987-2021)**
- **SW parameters are taken from the OMNI database**
- **Geomagnetic activity – Kp- and Ap -indices**
- **Dst-index**

ftp://ftp.swpc.noaa.gov/pub/lists/particle/

ftp://spdf.gsfc.nasa.gov/pub/data/omni/high_res_omni

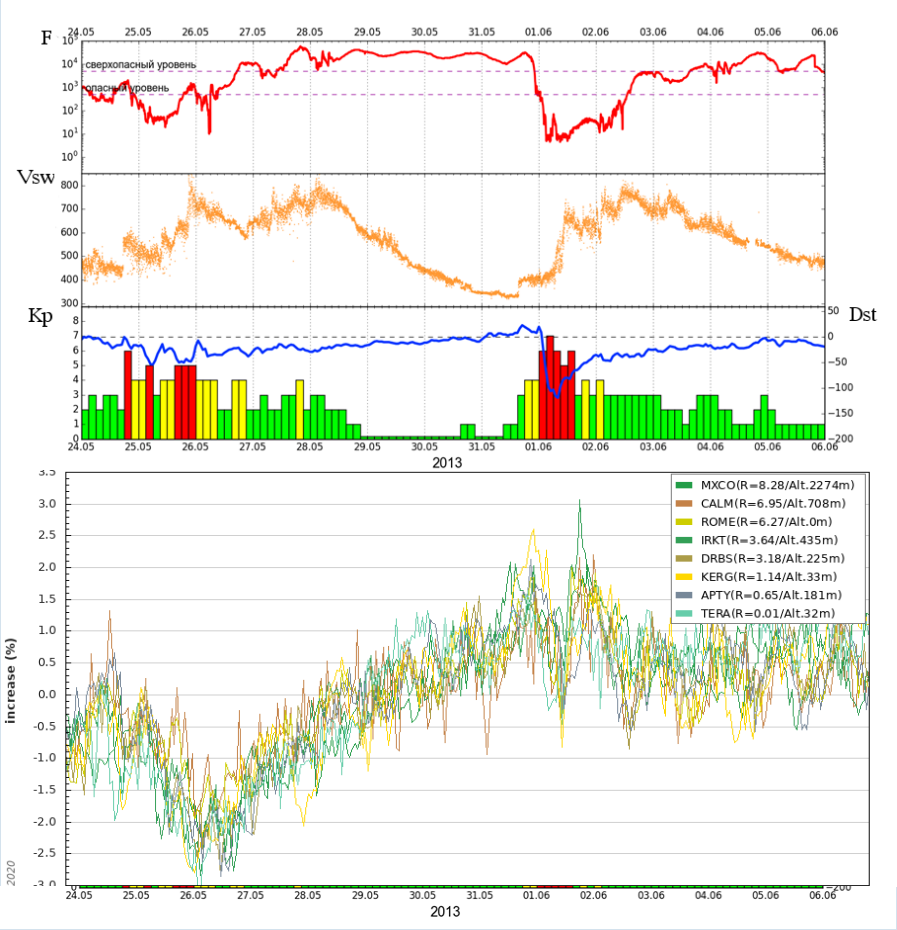
ftp://ftp.gfz-potsdam.de/pub/home/obs/kp-ap/wdc

http://wdc.kugi.kyoto-u.ac.jp

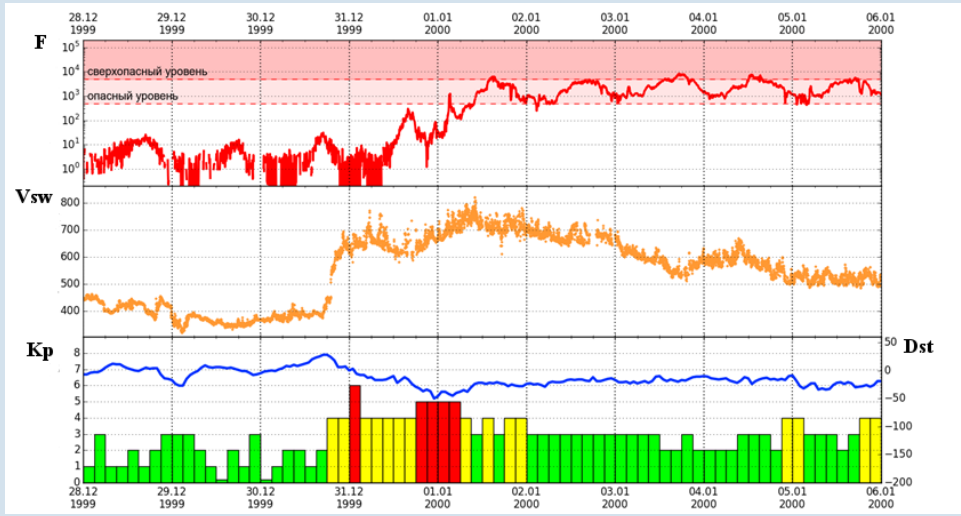
The SGA database is updated daily

TYPICAL EXAMPLES OF ELECTRON ENHANCEMENT EVENTS

In this work, we assumed that the electron flux begins to grow when the daily fluence exceeds 10^8 electrons $(cm^2\ sr\ day)^{-1}$. Increases of this level are typically considered dangerous.



The example of high-energy (> 2 MeV) electron flux behavior and other parameters in May-June 2013.



The example of high-energy (> 2 MeV) electron flux behavior and other parameters in December 1999 - January 2000.

We acknowledge the NMDB database (www.nmdb.eu), founded under the European Union's FP7 programme (contract no. 213007), for providing data

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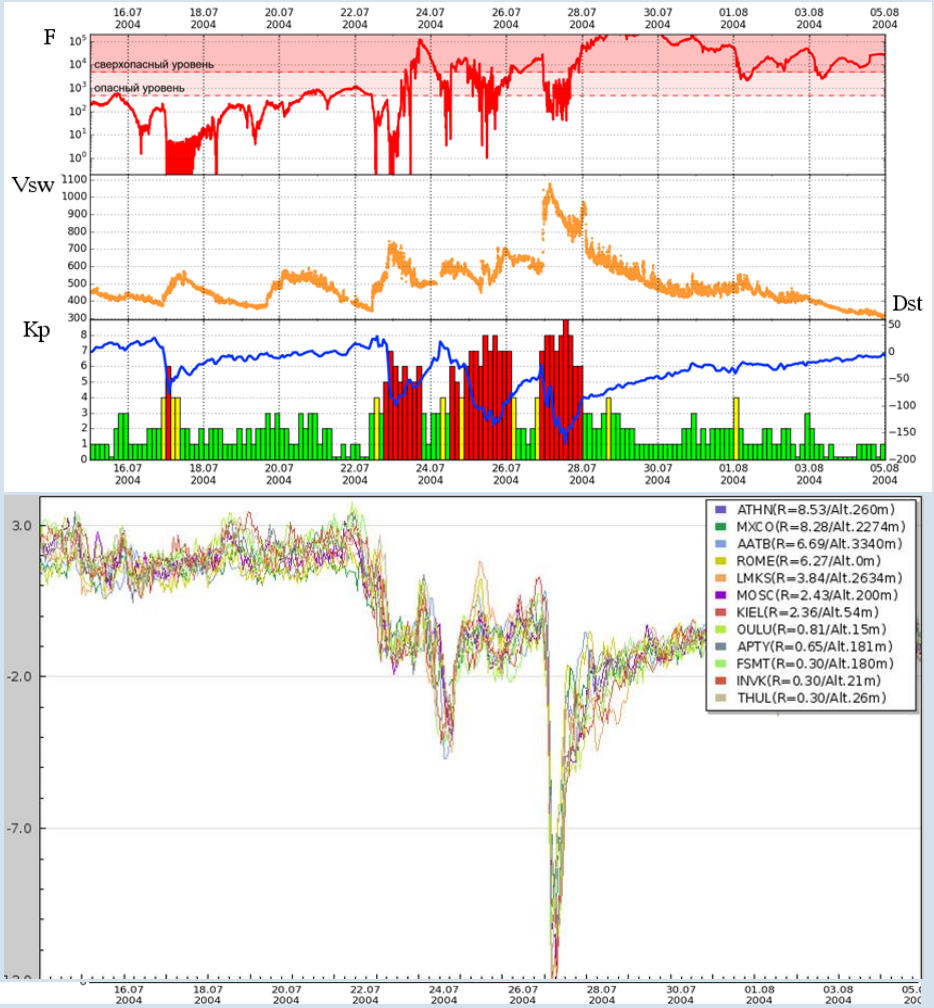
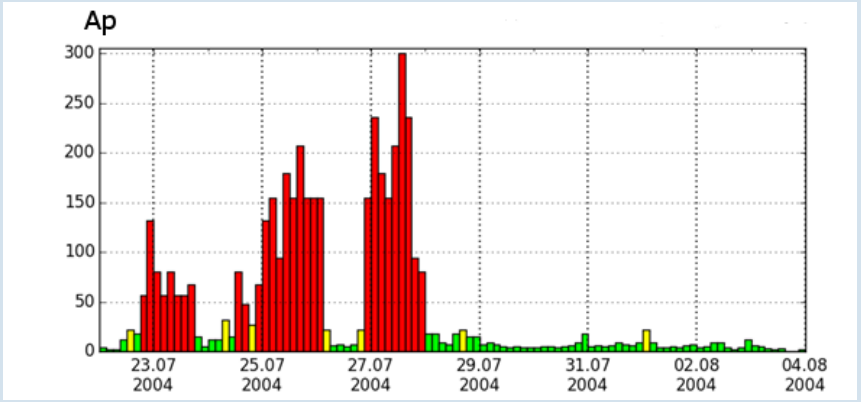
THE EVENT WITH THE MAXIMUM ELECTRON FLUENCE





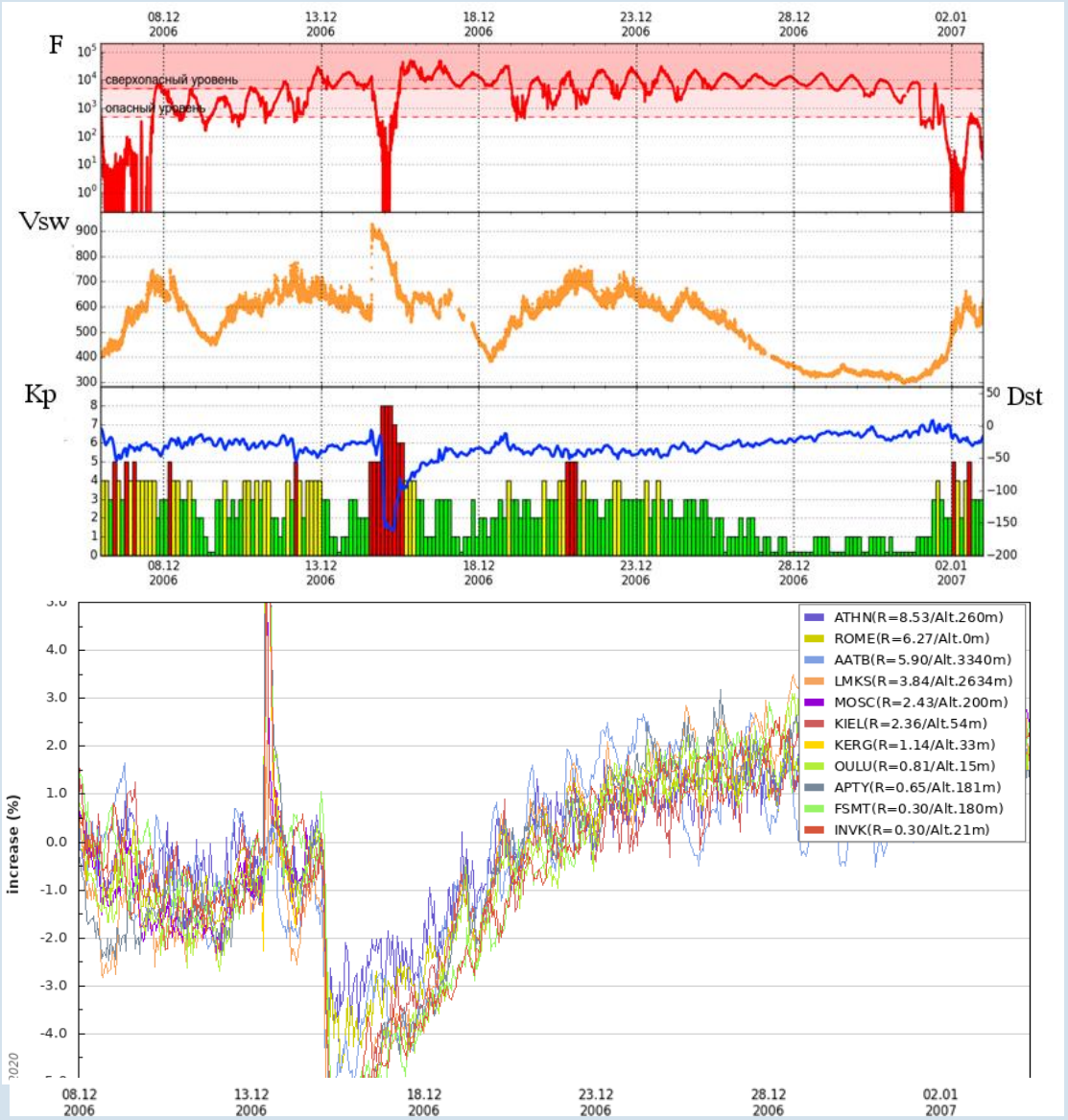
FD ~ 12 %, Severe magnetic storm (Ap = 300, Kp=9-)

The maximum fluence for these 21 years was 9.3 × 10^9 electrons $(cm^2\ sr\ day)^{-1}$, which was observed on July 29, 2004.

NMDB: Real-Time Database for high-resolution Neutron Monitor measurements (www.nmdb.eu)

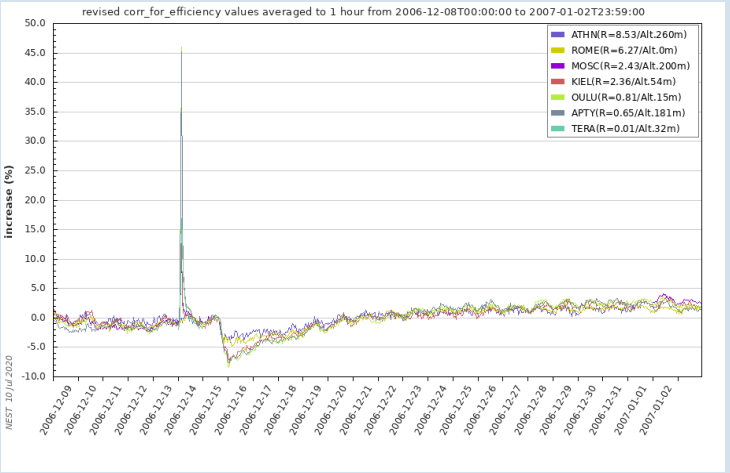
We acknowledge the NMDB database (www.nmdb.eu), founded under the European Union's FP7 programme (contract no. 213007), for providing data

THE LONGEST EVENT IN DECEMBER 2006



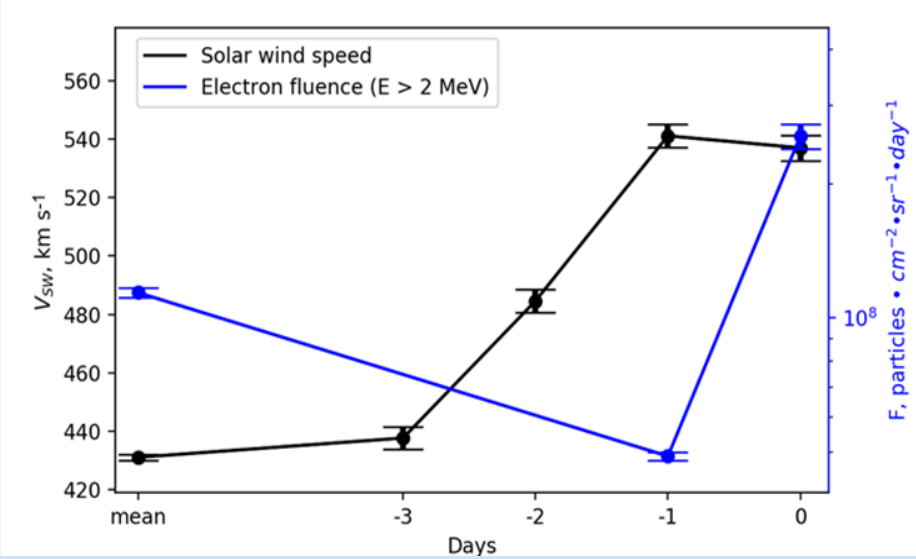
Electron enhancements generally last longer than 1 day, while the longest event (22 days long) was observed from December 10 to December 31, 2006.

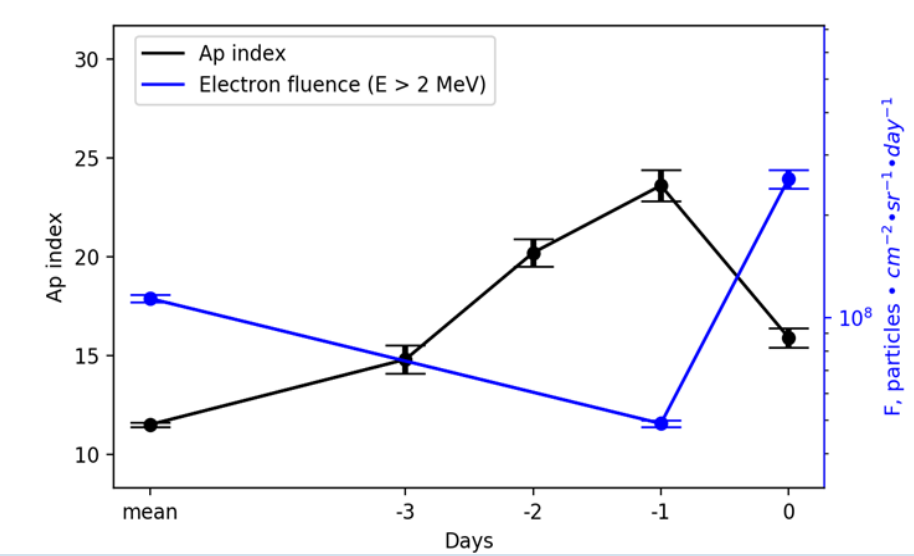
FD ~ 5 %, Extreme magnetic storm Kp=8



GLE 70
2006.12.13

THE TYPICAL BEHAVIOR OF THE SOLAR WIND VELOCITY AND THE AP-INDEX OF GEOMAGNETIC ACTIVITY BEFORE THE ELECTRON FLUX ENHANCEMENT AND DURING ITS ONSET (1987-2021)





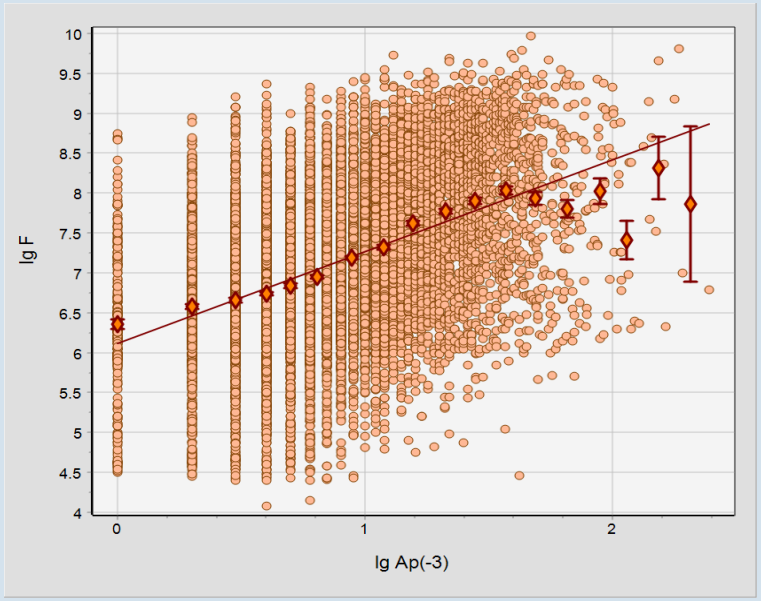
Behavior of the averaged SW velocity and diurnal fluence of magnetospheric electrons before the beginning of electron flux enhancements

Behavior of the averaged Ap-index of geomagnetic activity and diurnal fluence of magnetospheric electrons before the beginning of electron flux enhancements

Kryakunova et al. Average characteristics of high-energy magnetospheric electron flux enhancements and the parameters of near-Earth and interplanetary medium in 1987-2021. Monthly Notices of the Royal Astronomical Society, 2022.

Relationship with Geomagnetic Activity Indices

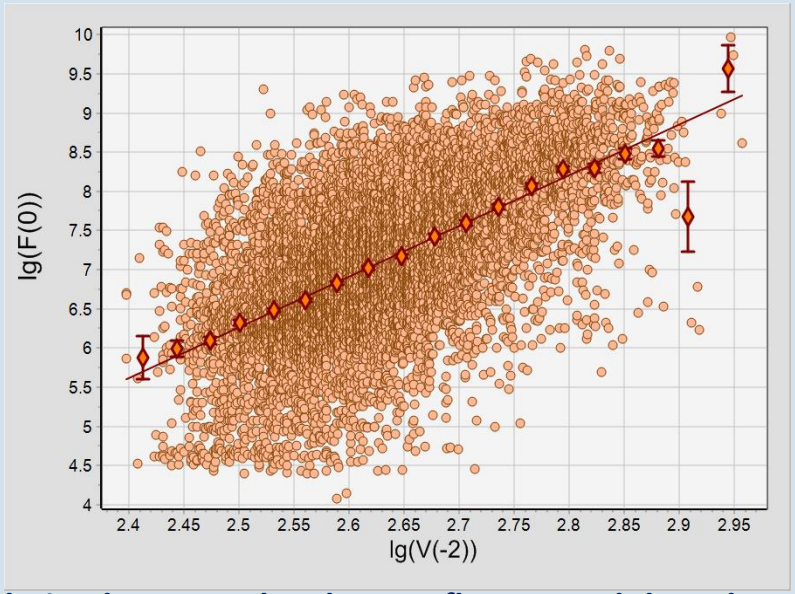
The maximum correlation coefficient is observed with the Ap-index measured 2 – 3 days earlier.



Relationship between the electron fluence and the geomagnetic activity Ap-index measured 3 days earlier

Relationship with solar wind speed

Calculated the linear regression coefficients for the relationship between the electron fluence and the solar wind speed with a shift from 0 to 3 days. The corresponding correlation coefficients are shown in Table



Correlation between the electron fluence and the solar wind speed with a shift of 2 days in the case of a power representation.

Correlation coefficients between the electron fluence and various parameters

Parameter	0 day	-1 day	-2 day	-3 day	- 4 day
Electron fluence	-	0.792±0.005	0.55±0.01	-	-
Ap-index	0.03±0.01	0.17±0.01	0.30±0.01	0.32±0.01	0.29±0.01
Solar wind speed	0.24±0.01	0.37±0.01	0.43±0.01	0.38±0.01	-

Kryakunova et al. A statistical relationship between the fluence of magnetospheric relativistic electrons and interplanetary and geomagnetic characteristics. Advances in Space Research. 2022.

PREDICTIVE MODEL

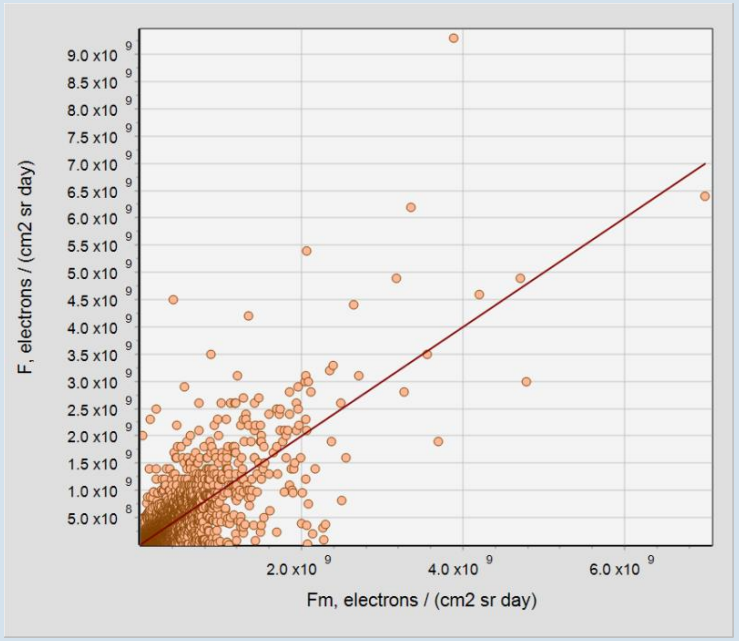
To create an effective predictive model for the fluence of high-energy magnetospheric electrons, we decided to combine the indices associated with the prehistory of the fluence with indices that include the solar wind speed and the level of geomagnetic activity.
A multiparameter model of the high-energy magnetospheric electron fluence can be presented as follows:

$$F_M = a + b \cdot F + c \cdot V + d \cdot Ap$$

Such a model with three different indices gave the best results (correlation coefficient KN=0.82) when using

1. **previous day electron fluence – F(-1),**
2. **previous day solar wind velocity – V(-1),**
3. **geomagnetic activity Ap-index measured 2 days earlier – Ap(-2).**

Note that the values of the correlation coefficient given in Table for Ap(-3) are somewhat larger than for Ap(-2), but Ap(-2) showed better results in the simulation.



Together with the statistical errors of the regression coefficients for the selected parameters, we have:

$$F_M=(-1.29\pm0.11)\cdot10^8 + (0.882\pm0.010)\cdot F(-1) + (1.62\pm0.21)\cdot10^6 \cdot V(-1) + (3.65\pm0.38)\cdot10^5 \cdot Ap(-2)$$

Kryakunova et al. A statistical relationship between the fluence of magnetospheric relativistic electrons and interplanetary and geomagnetic characteristics. Advances in Space Research. 2022.

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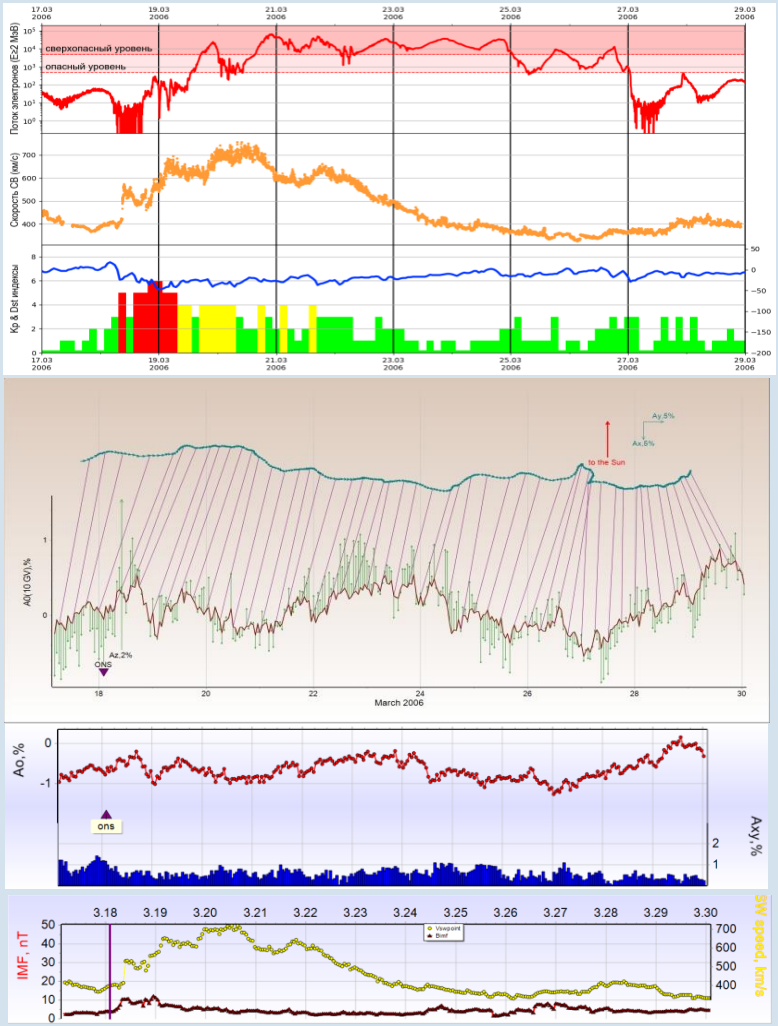
The features of the behavior of the density and vector anisotropy of galactic cosmic rays according to the data of the worldwide network of neutron monitors, before and during electron enhancements

CH



An enhancement in magnetospheric electron flux and the state of the interplanetary and near-Earth medium on March 17-30, 2006

An enhancement in magnetospheric electron flux and the state of the interplanetary and near-Earth medium on March 4-13, 2007

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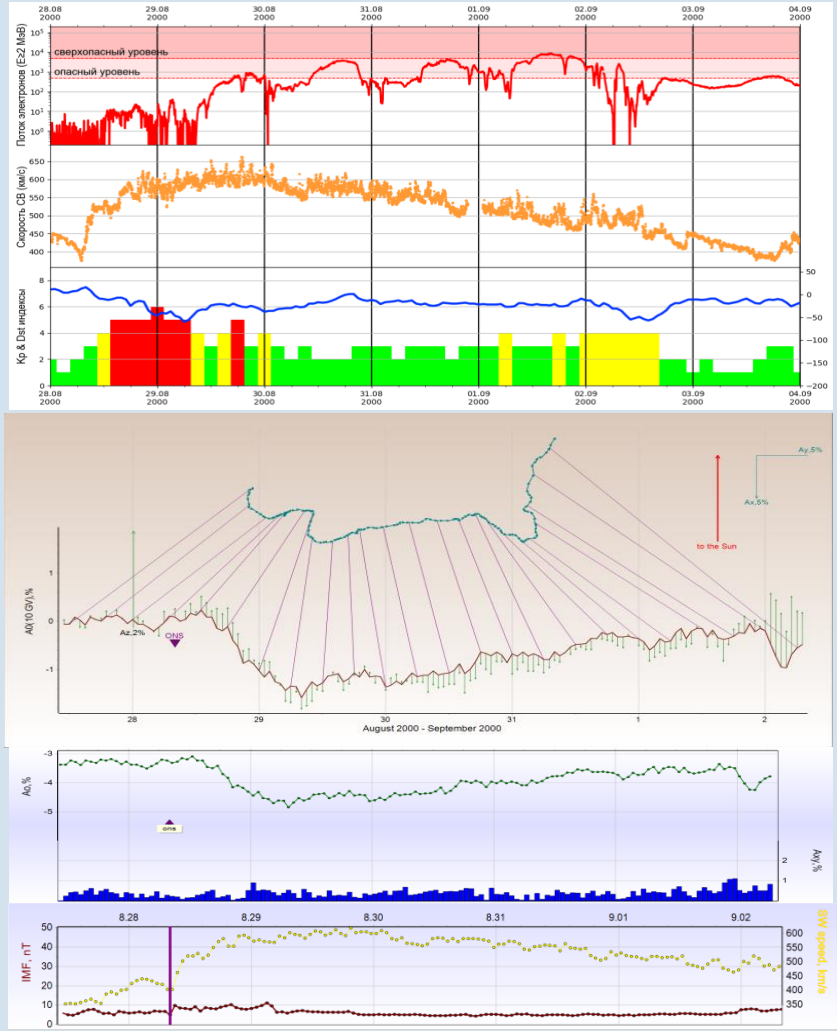
The features of the behavior of the density and vector anisotropy of galactic cosmic rays according to the data of the worldwide network of neutron monitors, before and during electron enhancements



CH + DSF

The event of a dangerous increase in magnetospheric electrons on August 29 - September 2, 2000 is accompanied by a Forbush effect of more than 1% and disturbance of the geomagnetic situation to the level of a moderate magnetic storm.

The vector Axy anisotropy has a more curved appearance with the rotation of the vectors due to the propagation of galactic cosmic rays through the coronal mass ejection (CME) from the disappearance of the solar filament (DSF).

An enhancement in magnetospheric electron flux and the state of the interplanetary and near-Earth medium on August 27 – September 2, 2020

The features of the behavior of the density and vector anisotropy of galactic cosmic rays according to the data of the worldwide network of neutron monitors, before and during electron enhancements

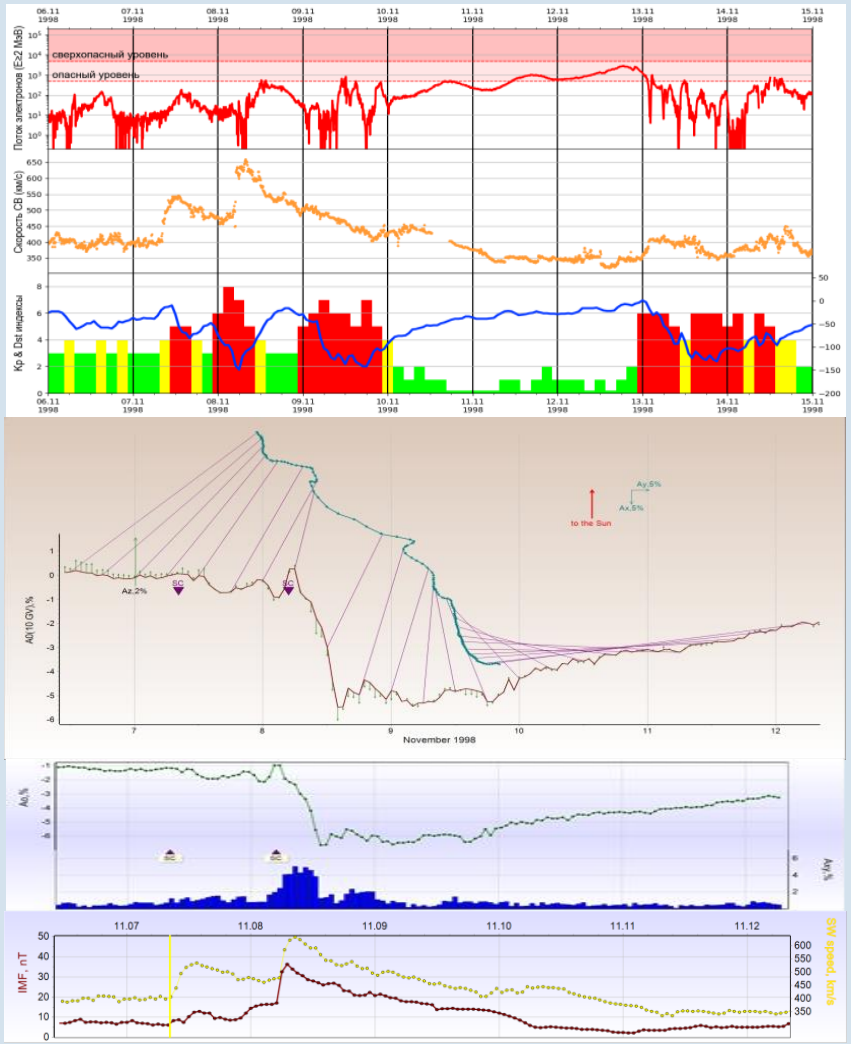
CH + SF

The event of a dangerous enhancement in magnetospheric electrons on August 27 - September 2, 1998 is associated with the influence on near-Earth space of a high-speed solar wind stream from a coronal hole and a coronal mass ejection from a solar flare that occurred on August 24, 1998 at 21:50 UTC.

This event was accompanied by a Forbush effect of about 7% and disturbance of the geomagnetic situation to the level of a very large magnetic storm. The vector Axy anisotropy has a more curved appearance with kinks due to the propagation of galactic cosmic rays through a coronal mass ejection (CME) from a solar flare.

An enhancement in magnetospheric electron flux and the state of the interplanetary and near-Earth medium on August 25 – September 2, 1998

The features of the behavior of the density and vector anisotropy of galactic cosmic rays according to the data of the worldwide network of neutron monitors, before and during electron enhancements



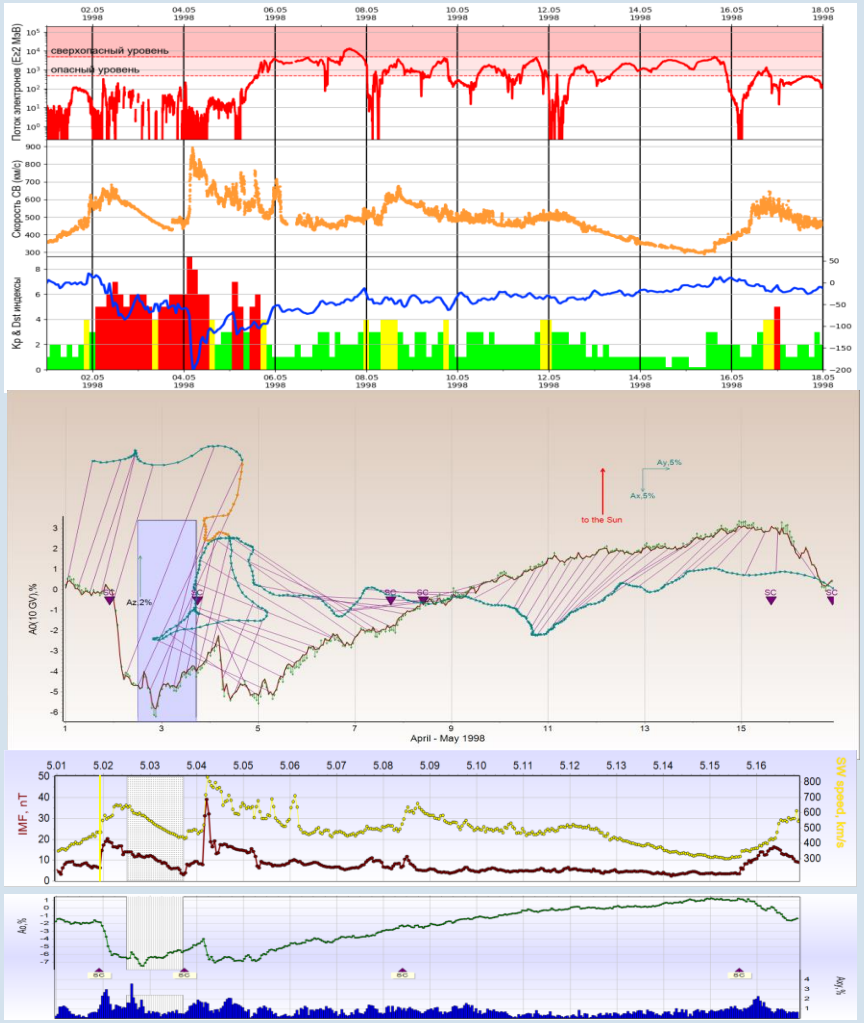
SF +DSF

The event of a dangerous enhancement in magnetospheric electrons on November 11-12, 1998 is associated with the influence on near-Earth space of a coronal mass ejection from a solar flare that occurred on November 4, 1998 at 07:13 UTC and a coronal mass ejection from the disappearance of the solar filament.

This event was accompanied by a Forbush effect of about 6% and disturbance of the geomagnetic situation to the level of a very large magnetic storm. The vector Axy anisotropy has a complex curved appearance due to the propagation of galactic cosmic rays through coronal mass ejections (CMEs) from a solar flare and the disappearance of the filament.

An enhancement in magnetospheric electron flux and the state of the interplanetary and near-Earth medium on November 6-12, 1998

The features of the behavior of the density and vector anisotropy of galactic cosmic rays according to the data of the worldwide network of neutron monitors, before and during electron enhancements



An enhancement in magnetospheric electron flux and the state of the interplanetary and near-Earth medium on May 5-15, 1998

The event of a dangerous enhancement in magnetospheric electrons on May 5-15, 1998 is associated with the influence on near-Earth space of a coronal mass ejection from a solar flare that occurred on April 29, 1998 at 16:06 UT.

This event was accompanied by a Forbush effect of about 6% and a disturbance of the geomagnetic situation to the level of an exceptionally large magnetic storm.

CONCLUSIONS

From the analysis of 453 events of high-energy magnetospheric electron flux enhancements, in which the values of the GCR density and anisotropy beyond the magnetosphere boundary are calculated, it can be concluded that:

- ***The vast majority of electron flux enhancements are associated with the arrival of HSS from CHs to the Earth. In these events, the flux of high-energy electrons exceeds the high dangerous level most often. In this case, FEs of small magnitude (about 1%) and a smooth behavior of the vector anisotropy are observed;***

- ***In events associated with other additional solar sources (two types of CMEs), an important role in increasing the electron flux is still played by HSS from CHs. In such events, a more complex, curved behavior of the GCR vector anisotropy, large magnitudes of FEs in the CR density, and an enhancement in the values of the equatorial component of the CR anisotropy are observed;***

- ***Single events of enhancements in high-energy electron flux caused by CMEs & solar flares are observed, however, despite large effects in the geomagnetic field, such CMEs do not cause enhancements to high dangerous levels in the electron flux.***

Thank you for your attention !

Tamgaly-Tas Petroglyphs «Man-Sun» in Kazakhstan